Reduction in Soil Penetration Resistance for Suction-assisted Installation of Bucket Foundation in Sand

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Agenda

- Concept of bucket foundation
- CPT-based method for suction installation
- 1G laboratory tests on jacking and suction installation
- Results and discussion
- Conclusions

Concept of bucket foundation

- Suction bucket foundation - concept

- Success in suction installation

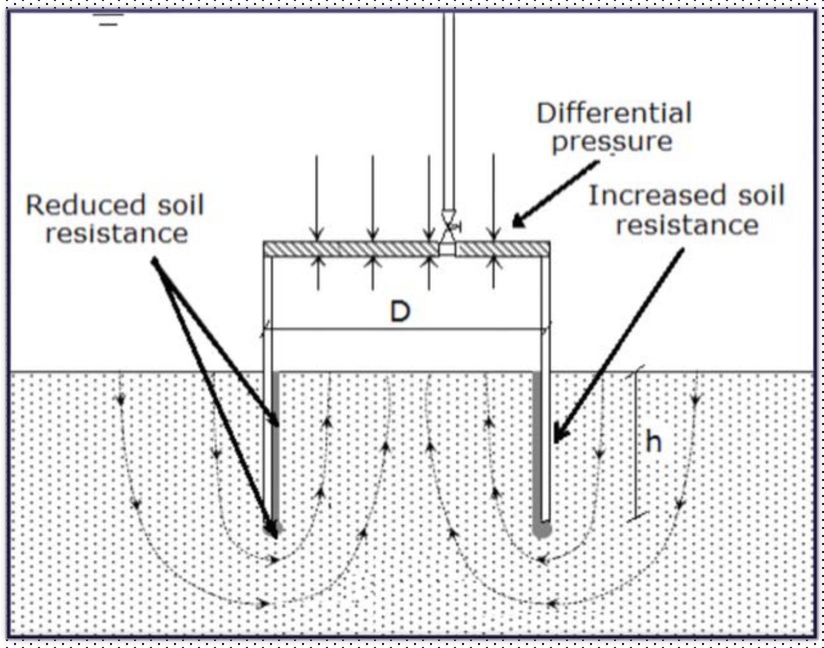

Fig.1 Seepage flow around the bucket skirt [1]

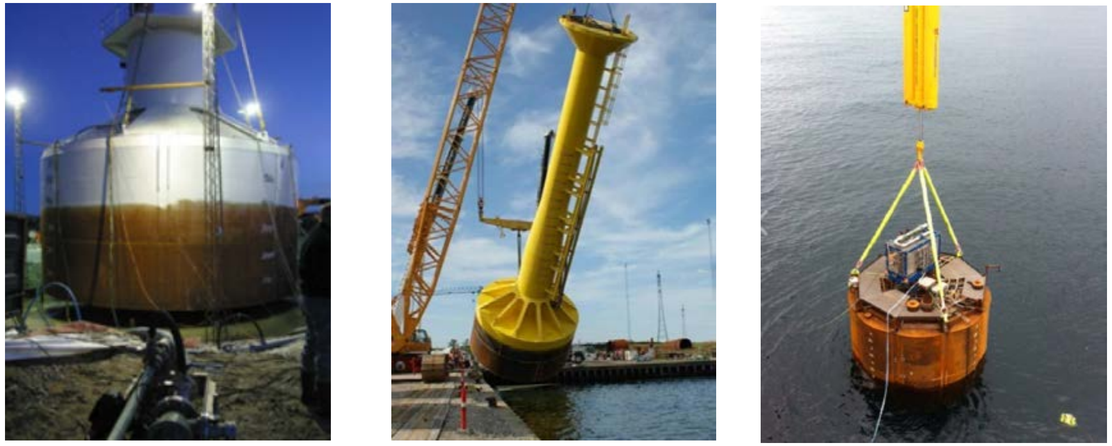

Fig.2 Case studies from Universal Foundation, Denmark [2]

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CPT-based method for suction installation

Empirical coefficients k_f and k_p

- Soil penetration resistance

$$R_{soil} = F_{in} + F_{out} + Q_{tip}$$

$$F_{in} = \pi D_i k_f \int_0^h q_c(h)\,dh$$
$$F_{out} = \pi D_o k_f \int_0^h q_c(h)\,dh$$
$$Q_{tip} = A_{tip} k_p q_c(h)$$

- Reduction due to the seepage flow

Reduction factors: $\beta_{in}, \beta_{out}, \beta_{tip}$

- $F_{in} = \beta_{in} \pi D_i k_f \int_0^h q_c(h)\,dh$
- $F_{out} = \beta_{out} \pi D_o k_f \int_0^h q_c(h)\,dh$
- $Q_{tip} = \beta_{tip} A_{tip} k_p q_c(h)$

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Test set-up and model of bucket foundation

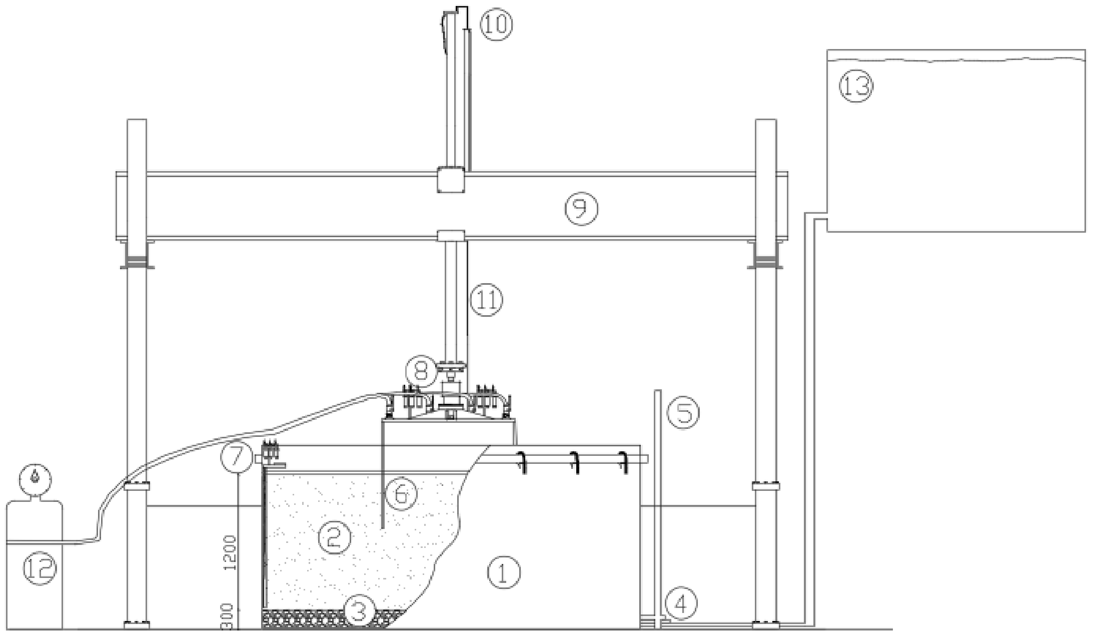

Fig.3 Test set-up: (1) Soil container, (2) Saturated sand, (3) Saturated gravel, (4) Drainage system: pipes and valves, (5) Ascension pipe, (6) Bucket foundation, (7) Beam with pore pressure transducers, (8) Load cell, (9) Loading frame, (10) hydraulic piston, (11) Displacement transducer, (12) Vacuum pump, (13) Water tank

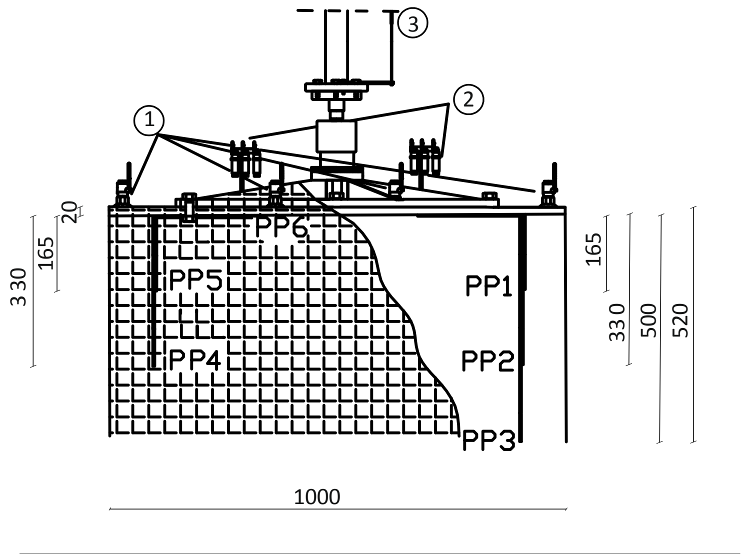

Fig.4 Bucket foundation model: (1) valves, (2) pore pressure transducers, (3) displacement transducer, (PP1-PP6) measurements points

1G laboratory tests on jacking and suction installation

- Soil preparation, $I_D = 90\%$
- CPT before and after installation
- Test procedure and measurements
  - Jacking installation
  - Suction installation

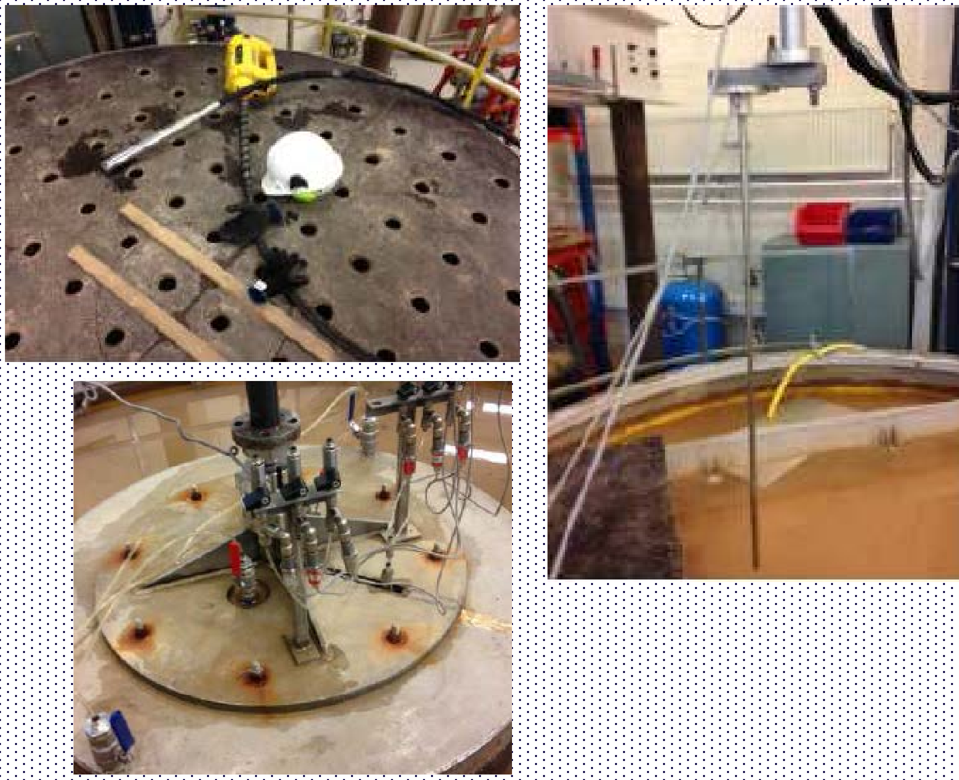

Fig.5 Photos from laboratory procedure [3]

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Empirical coefficients k_p and k_f

- Optimization of 4 jacking installation tests

$$R_{soil} = F_{in} + F_{out} + Q_{tip}$$

$$F_{in} = \pi D_i k_f \int_0^h q_c(h)\, dh$$

$$F_{out} = \pi D_o k_f \int_0^h q_c(h)\, dh$$

$$Q_{tip} = A_{tip} k_p q_c(h)$$

Empirical coefficients	Lowest expected	Highest expected
k_p	0.3	0.6
k_f	0.001	0.003

Tab.1 Recommended values of empirical coefficients for sand from DNV

	Value of k_f	Reference
Chosen coefficient for optimization	0.004	Lehance et al. 2005 [4]
	0.0023	Senders and Randolph 2009 [5]
	0.0053	Andersen 2008 [6]

Tab.2 Chosen values of k_f for optimization

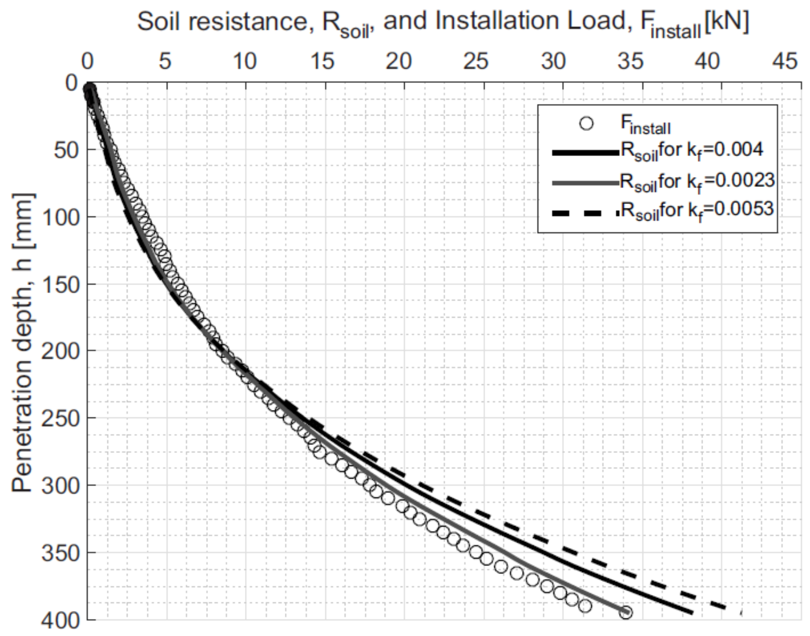

Fig.6 Soil resistance compared with installation load (test no.06)

Test no.	k_f	k_p	R^2
06	0.0023	0.38	0.991
07	0.0023	0.36	0.998
08	0.0023	0.39	0.998
10	0.0023	0.33	0.994

Tab.3 Chosen values of empirical coefficients

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Empirical coefficients k_p and k_f

- Comparison of calculated resistance with applied load

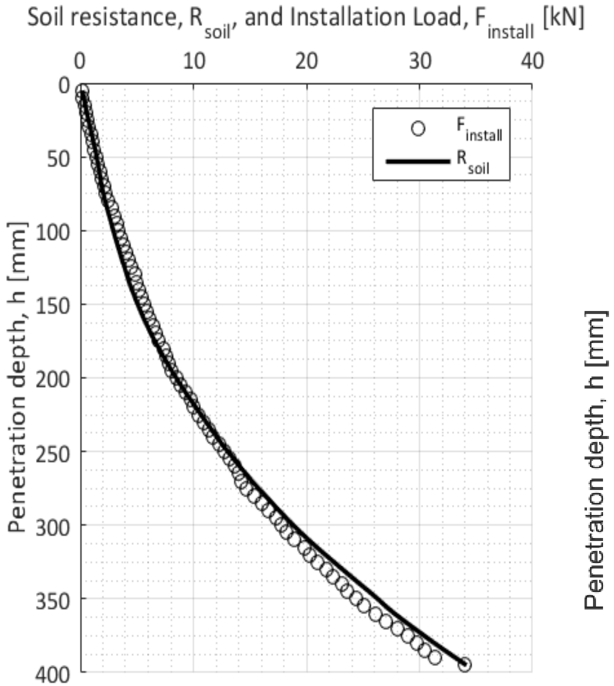

Fig.7 Test no.06 - $k_p = 0.38$, $k_f = 0.0023$

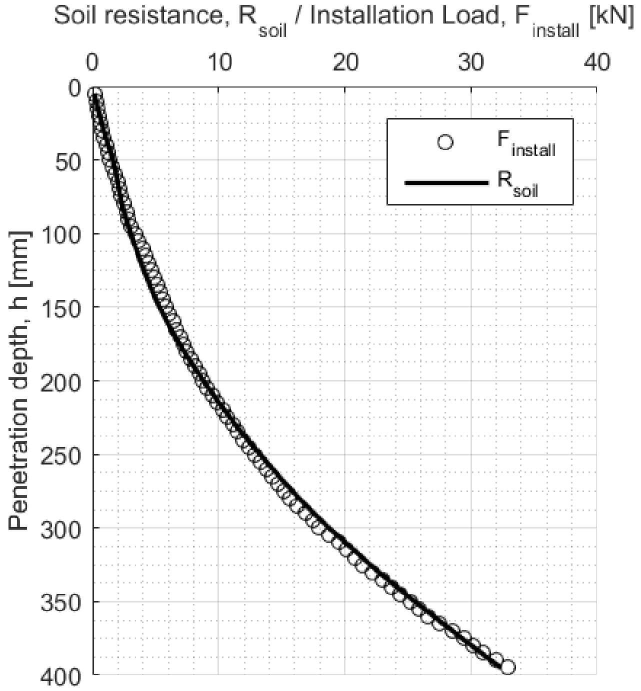

Fig.8 Test no.07 - $k_p = 0.36$, $k_f = 0.0023$

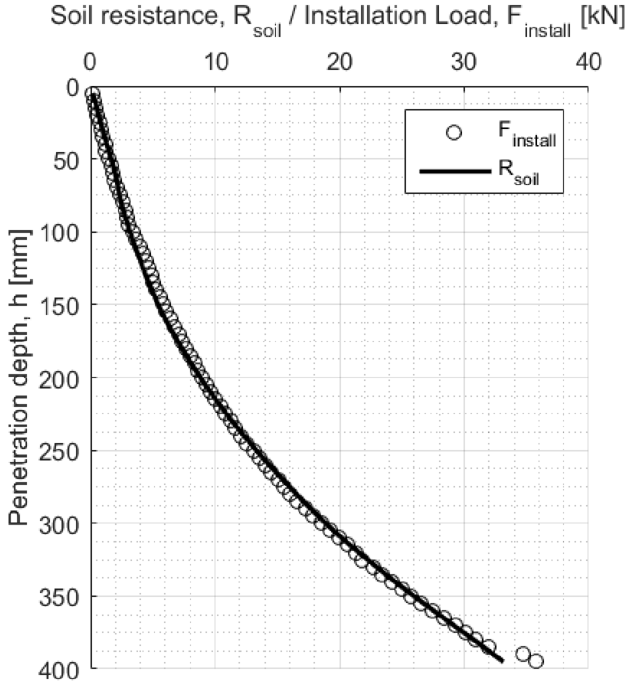

Fig.9 Test no.08 - $k_p = 0.39$, $k_f = 0.0023$

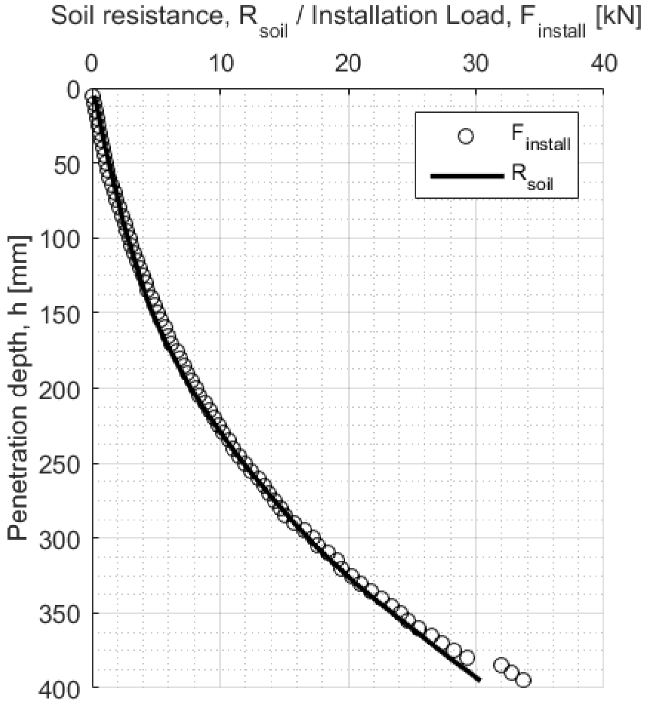

Fig.10 Test no.10 - $k_p = 0.33$, $k_f = 0.0023$

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Soil resistance reduction factors $\beta_{in}, \beta_{out}, \beta_{tip}$

Optimization of 6 suction installation tests

- β - factors

$$\beta_{in} = 1 - r_{in} \cdot \exp\left(\frac{p}{p_{crit}}\right),$$
$$\beta_{tip} = 1 - r_{tip} \cdot \exp\left(\frac{p}{p_{crit}}\right),$$
$$\beta_{out} = 1$$

- Critical suction pressure

$$i_{exit} = \frac{p}{s \cdot \gamma_w}$$
$$\left(\frac{s}{h}\right)_{exit} = 1.25\left(\pi - \operatorname{atan}\left(2.5 \cdot \left(\frac{h}{D}\right)^{0.74}\right)\right) \cdot \left(2 - \frac{1.8}{\pi}\right)$$
$$i_{crit} = \frac{\gamma'}{\gamma_w}$$
$$\frac{p_{crit}}{\gamma' \cdot D} = \left(\frac{h}{D}\right) \cdot \left(\frac{s}{h}\right)$$

Adjusted for:
- boundary conditions
- increased inside soil permeability

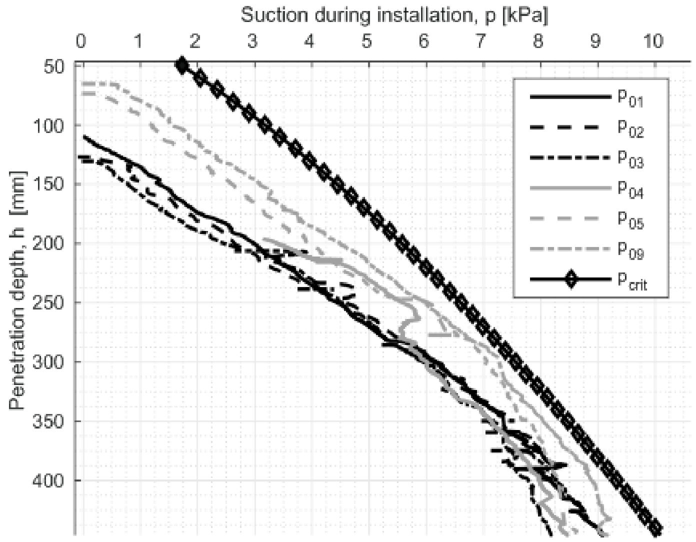

Fig.11 Applied pressure for all suction installation tests

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Test no.	For $k_p = 0.33$			For $k_p = 0.39$		
	r_{in}	r_{tip}	R^2	r_{in}	r_{tip}	R^2
01	1.0	0.11	0.97	1.0	0.16	0.95
02	1.0	0.14	0.85	1.0	0.19	0.74
03	1.0	0.15	0.78	1.0	0.19	0.72
04	1.0	0.15	0.89	1.0	0.19	0.90
05	1.0	0.1	0.88	1.0	0.14	0.89
09	1.0	0.09	0.86	1.0	0.13	0.88

Tab.4 Chosen values of reduction factors

$$\beta_{in} = 1 - r_{in} \cdot \exp\left(\frac{p}{p_{crit}}\right),$$

$$\beta_{tip} = 1 - r_{tip} \cdot \exp\left(\frac{p}{p_{crit}}\right),$$

$$\beta_{out} = 1$$

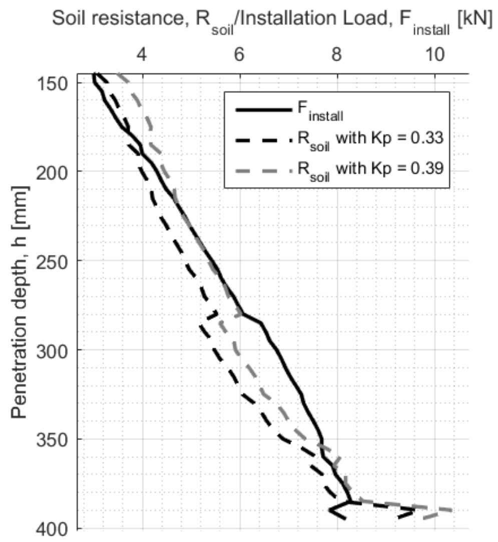

Fig.12 Test no.01

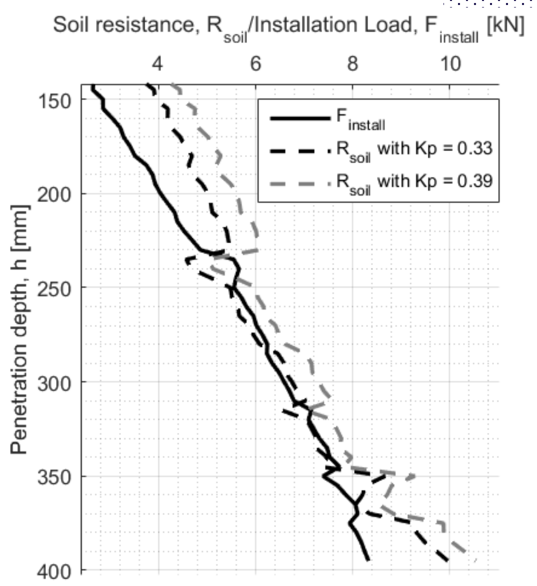

Fig.13 Test no.02

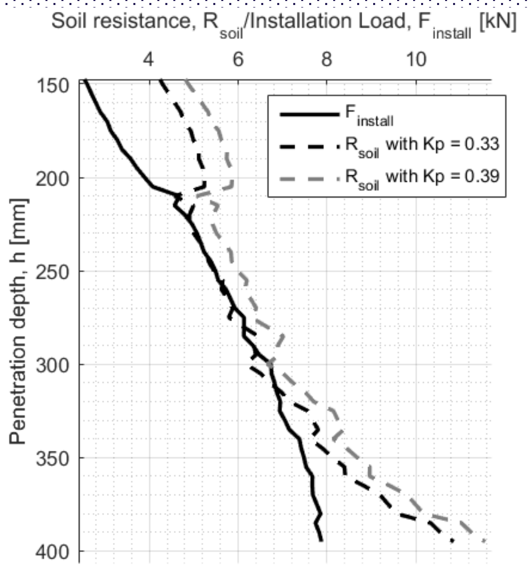

Fig.14 Test no.03

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Comparison between the suction and jacking installation

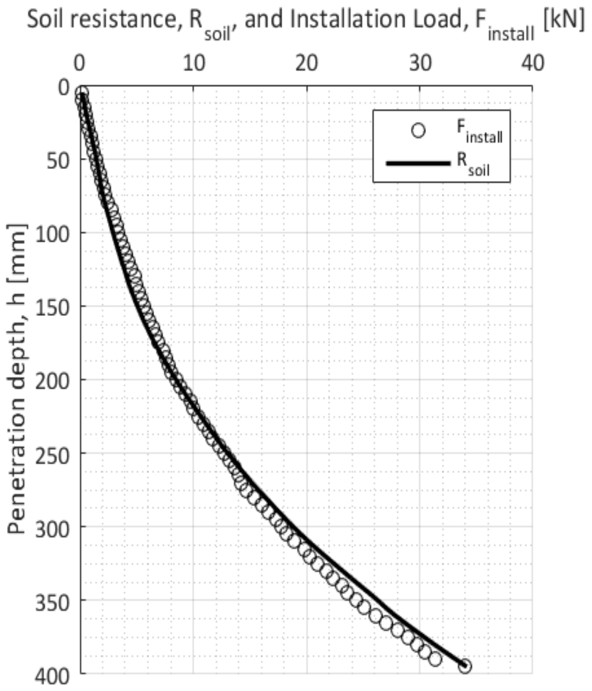

Fig.16 Test no.06 – jacking installation

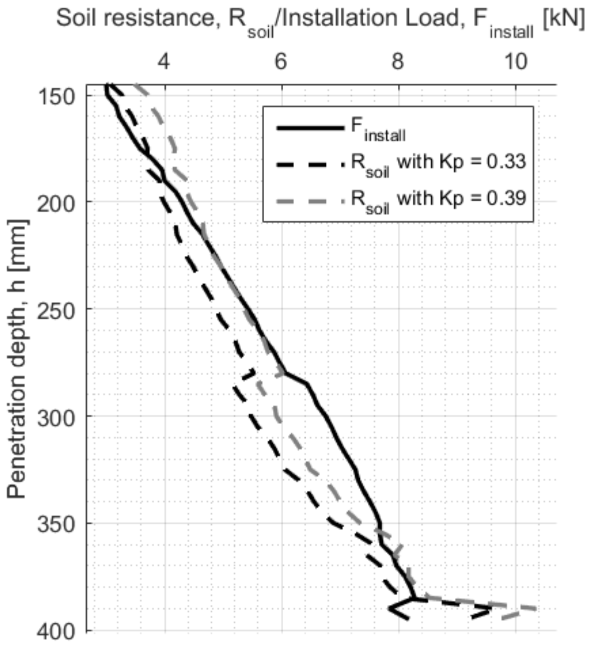

Fig.17 Test no.01 – suction installation

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Conclusions

- Success of laboratory tests for suction installation
  -reduction in soil penetration resistance
  - loosening of inside soil plug

- CPT-based method for calculation of soil penetration resistance
  - suggested values for parameters k_p and k_f
  - reduction in resistance: factors β_{in}, β_{tip}

- Critical suction

Thank you for your attention!

References:

[1] Koteras A.K., Ibsen L.B. and Clausen J.(2016). Seepage study for suction installation of bucket foundation in different soil combinations. In Proc., 26th Int. Ocean and Polar Eng. Conf., 26 june-2 july, Rhodos, Greece, pp.697-704. Int. Society of Offshore and Polar Engineers.

[2] http://www.universal-foundation.com

[3] Koteras A.K. (2017) Set-up and test procedure for suction installation and uninstallation of bucket foundation. DCE Technical Report, No. 63, Department of Civil Engineering, Aalborg University, Denmark

[4] Lehance B.,Schneider J. and Xu X. (2005) The UWA-05 method for prediction of axial capacity of driven piles in sand. In Proc., Int. Symp. On Frontiers in Offshore Geotechnics (IS-FOG), Perth, Australia, pp. 19-21.

[5] Senders M. and Randolph M. (2009). CPT-based method for the installation of suction caissons in sand. J. Geotech. And Geoenv. Eng. 135(1), 14-25.

[6] Andersen K.H., Jostad H.P. and Dyvik R. (2008) Penetration Resistance of Offshore Skirted Foundations and Anchors in Dense Sand. J. Geotechnical and Geoenvironmental Engineering, 134, pp 106-116

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